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A review on promoting share of renewable energy by green-trading mechanisms in power system

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ABSTRACT

In order to promote the development of renewable energy power generation, many countries have issued corresponding policies. Meanwhile, some green-trading mechanisms have been implemented in power industry. And this paper has mainly presented a review on promoting share of renewable energy by green-trading mechanisms in power system with a focus on promotion effects of three mechanisms: feed-in tariff, renewable portfolio standard and emission trading scheme. Apart from a review, summaries, comparisons, and an outlook for future study are also presented. Our review suggests that feed-in tariff and renewable portfolio standard can effectively increase the share of renewable energy power and lead to renewable resource diversity. In addition, emission trading also provides stimulus for development of renewable energy besides mitigation of carbon emission.

Contents

1. Introduction

With the continuous development of economy and society, nowadays many environmental and energy problems have arose. With regard to the environment, a series of issues about climate change, like global warming, have threatened human survival due to the large amounts of greenhouse gas emissions. Carbon emission issues in China are also in an urgent situation. Table 1 shows relevant data published by Global Carbon Project, and we can see that while per-capita emissions are not too high, total emissions in China are the highest globally, with a share of 27%. Therefore, the control of emissions of carbon dioxide and other greenhouse gases is very important and urgent.

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As for energy,the traditional fossil energy is running out and may be extinct in the coming decades. Considering its potential safety hazard, many countries begin to abandon or delay their construction of nuclear power plant. So faced with the increasingly severe global energy and environmental problems, there is a practical solution for all countries, to develop and utilize renewable energy for the sake of energy security and sustainable development.

Many countries have set clear development strategies for the development of renewable energy. The European Union has put forward a goal that the share of renewable energy in total energy consumption should reach 20% by 2020, and the goal for France, Germany and Britain is 23%, 18% and 15% respectively. Japan's objective is that the renewable energy power generations must meet 20% of its power demand by 2020 [2]. Besides, China aims to raise its renewable energy share to 20% by 2020.

As one of the major energy-consuming industries, power sector has an important role in the achievement of renewable energy target. However, the share of renewable energy in electricity mix is rather low. The data in Fig. 1 is published by China Electricity Council, from which we notice that the figure we notice that the proportion of thermal power is as high as 69% [3], compared with low ratio of green power such as solar and grid-connected wind.

Table 1
Major emitters of carbon dioxide in 2012 [1].

Countries	Share (%)	Per-capita emissions (tC)
China	27	1.9
the USA	14	4.4
the EU (28 member states)	10	1.9
India	6	0.5

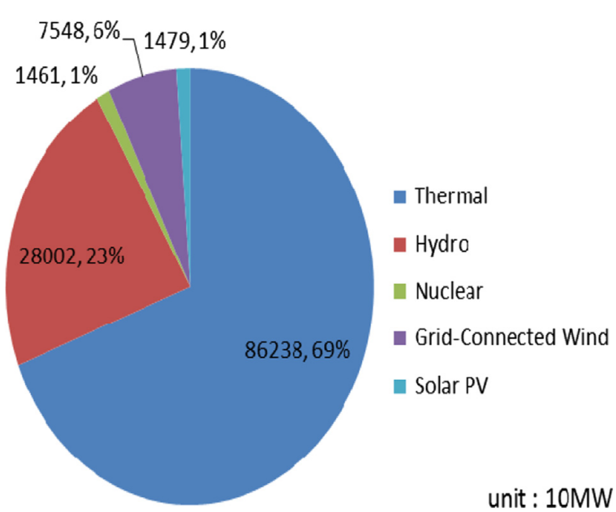


Fig. 1. National power generation capacity of China at the end of 2013.

Corresponding to the overall target for development of renewable energy, each country has set goals for renewable energy generations. However, compared to conventional technologies, renewable energy power generations cost relatively higher and are less mature [4]. In order to promote the development of renewable energy power generation, many countries have issued corresponding policies. Meanwhile, some green-trading mechanisms have been implemented in power industry to promote renewable energy generation and increase proportion of green power in installed capacity by means of marketization. So it is necessary to study green-trading mechanism in power system, which aims to promote renewable energy share.

Generally, promotion polices for renewable energy include feed-in-tariff, tending system, renewable portfolio standard, etc. Table 2 provides a classification of existing promotion strategies for renewables, in this paper, we focus on feed-in-tariff and tradable green certificate system and study their incentive effects on renewable energy generation. In addition, we discuss the impact of emission trading for the reason that it is one of green-trading mechanisms and besides mitigation of emission, it also provide benefits for renewable energy.

The remainder of this paper is organized as follows. Section 2 presents provisions and case studies of feed-in tariff together with a summary of its effect. In Section 3, we analyze the effects of renewable portfolio standard and tradable green certificates, and a comparison between renewable portfolio standard and feed-in tariff is also presented. Then the impacts of emission trading on renewable energy are introduced in Section 4. At last, Section 5 includes conclusions and an outlook for future work.

2. Feed-in tariff

Feed-in tariff (FIT) is a price-driven policy designed to accelerate investment in renewable energy technologies by offering guaranteed prices for electricity produced from renewable energy sources for fixed periods of time. These prices can be differentiated according to the type of technology, the size of the installation, the quality of the resource, and the location of the project. Table 3 presents feed-in tariff rate in Ukraine as an example.

Table 3
Average cost of electricity from renewables and feed-in tariff rates, Euro/kWh [6].

	Biomass CHP	Small hydro	Solar plants	Wind farms
Average cost	0.057	0.045	0.112	0.027
Feed-in tariff	0.127	0.044	0.243	0.066

Table 2
Fundamental types of promotion strategies [5].

	Direct		Indirect
	Price-driven	Quantity-driven	
Regulatory			
Investment focused	Investment incentives Tax credits Low interest/soft loans	Tendering system for investment grant	Environmental taxes Simplification of authorization procedures Connection charges, balancing costs
Generation based	(Fixed) Feed-in tariffs Fixed premium system	Tendering system for long term contracts Tradable green certificate system	
Voluntary			
Investment focused	Shareholder programs Contribution programs		Voluntary agreements
Generation based	Green tariffs		

And FIT typically include three key provisions: [7]

1) guaranteed grid access
2) long-term contracts
3) cost-based purchase prices.

2.1. Case studies

As of 2010, feed-in tariff policies had been enacted in over 50 countries [8], including Australia, Canada, China, Germany, Italy, Spain, the United Kingdom, etc.

The first successful FIT system for electricity from renewable energy sources (RES) was implemented in Germany and it has already been in place since 1991 when the "Electricity Feed-in Act" has been established. The Feed-In Law required electric utilities to connect RES generators to the grid and to buy the electricity at rates ranging from 65% to 90% of the average tariff for final customers [9]. As we can see in Fig. 2, this policy brought impressive growth of generation from RES. The share of gross electric consumption in 1990 was 3.4%, and it increased to 9.3% in 2004 [9]. In 2000 this act was substituted by the "Renewable Energy Act" and a target for the share of RES in electricity generation of 12.5% to be achieved by 2010 was set. Then, the act was amended in 2004 where a 20% target for the share of renewables in electricity generation up to 2020 was fixed [5].

There are many researchers studying the case of feed-in tariff in their respect countries. Ref. [10] addresses Portuguese feed-in tariff mechanism which is in force for supporting wind energy. Paper [11,12] analyzes feed-in tariff for solar PV in Malaysia. Ref. [13] introduces feed-in tariff for solar photovoltaic in Japan. In paper [14] the financial implications of the use of FITs in the Macedonian power system are presented. Paper [15,16] provides a survey and report on feed-in tariff in Canada. And paper [17] aims at discussing the benefits and some drawbacks of FIT schemes in Italy.

2.2. Simulation models

Various simulation models are used to analyze the effect of feed-in tariff, and they can be divided into two categories.

2.2.1. Economical analysis

Some researchers have turned to experimental economics to gain insight on the performance of FIT. In paper [18], a probabilistic model was developed with Monte Carlo techniques in order to evaluate the NPV of renewable energy projects under different support mechanisms. The results suggest that feed-in tariffs are useful to promote solar, wind, and other renewable technology by setting technology specific guaranteed tariffs. And a comparative economical analysis is performed in Ref. [19] calculating the cash flow, the net present value, the payback period, and the internal rate of return of the investment.

2.2.2. System dynamics model

System dynamics model is used in Ref. [20,21] to assess the effects of feed-in tariffs and to evaluate the capacity investments in renewable power generation sector. Results show that FIT scheme increases RES capacity investments and solar PV installation goal can be achieved by adopting FIT prices or subsidies.

2.2.3. Summary of the effects

Firstly, the predominant factor of FIT's high success in deploying renewable electricity is its clear and robust solution for integrating the supplies in existing power systems via purchasing obligation and priority dispatch and its guarantee of a fair and safe return on investment [22]. Long-time fixed prices could create a market stability to attract more investment and promote the industry. And it distinguishes between renewable energy (RE) technologies that are at different stages of development with different generation costs. The pricing differential also encourages RE development in a range of geographic locations [23]. Moreover, as the price is guaranteed, the FIT allows non-traditional developers into the

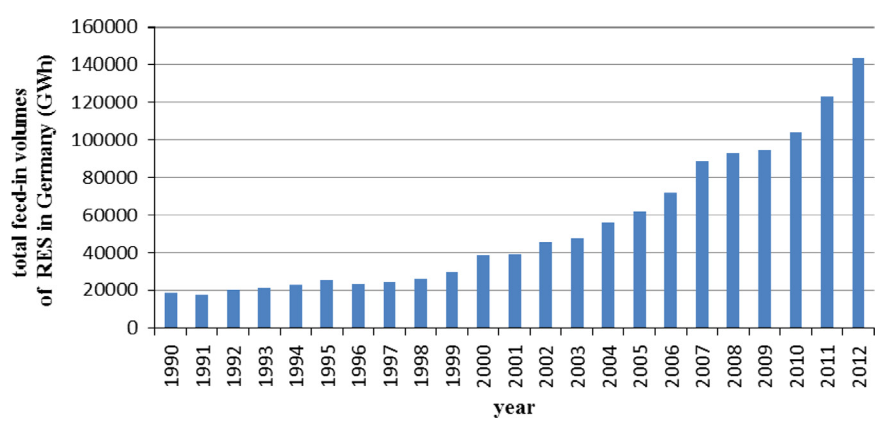


Fig. 2. Total feed-in volumes of RES from 1990 to 2012.

Table 4
Some important terms concerning RPS policy design feature.

Term	Description
Banding	Banding is a device in which different multiples of tradable certificates are issued for each unit of generation depending on the type of RES [31]
Carve-outs	Parts of a RPS market that are reserved for particular RES-E types
Tier	Multiple technology types are bundled together in "tiers" with similar effect
Banking	Hold TGC for extensive time to use it in the future
Borrowing	In some TGC markets, possibility of deferring the obligation for future exists whenever the TGCs are deficient, this is called borrowing
Penalties	In order to motivate compliance, states or countries that have enforceable standards will have penalties for utilities that fail to reach the specified targets

renewable energy market, such as households with solar panels and co-operatively owned wind turbines [24].

3. Renewable portfolio standard and tradable green Certificates

FIT does a good job at supporting RES development, however, a renewable portfolio standard mechanism is recommended to increase the share of renewable generations in a predictable way.

3.1. Overview

Renewable Portfolio Standard (RPS) (also known as Renewable Obligation (RO) in the United Kingdom) is a quantity-driven quota system that requires electricity suppliers to source a certain proportion of their electricity from renewable energy [25], and it aims to make sure that targets of renewable energy can be realized at the least cost and with a minimum of continuous administrative involvement by the government [26]. RPS programs are widely used at the state level in the United States, and have been implemented in Belgium, Australia, Canada, India, Italy, China, Japan, Poland, Sweden, and the United Kingdom [27].

To reduce the cost for meeting the requirement of RPS and increase flexibility, tradable green certificates (TGC) (also known as renewable energy certificates (REC)) are used to track and verify compliance [28]. In TGC market, for each unit of power that a qualified producer generates, a certificate or credit is issued. These certificates can then be sold either separately to energy supply companies or in conjunction with the underlying power [29].

In the specific implementation process, policy features will affect the effectiveness of RPS [30]. Some important features which are listed in Table 4 must be concerned about to design RPS and TGC policy.

Recently, RPS and TGC have been the subject of numerous academic researches. And the studies generally focus on four aspects:

1) General analysis of policy system
2) Comparisons with other promotion strategies for renewables
3) Case studies of status of RPS/TGC schemes in certain countries
4) The interaction between TGC and emission trading markets

3.2. Effects of RPS on renewable capacity

Overall, the research conducted on RPS and TGC has found mixed results of their effectiveness. Some studies report that RPS has an inconspicuous impact on renewable generation [32,33]. However, as far as renewable capacity is concerned, almost all of the studies show that the effect of RPS on renewable capacity is positive and significant.

While efforts of the policy often encourage increase of capacity from all renewable energy sources, wind power has received particular attention because it is the most dynamic renewable energy in the world and it is economically competitive in situations where the wind resource is plentiful.

RPS programs are widely implemented in states of USA, and Ref. [34] explores the key factors in 12 States in which a substantial amount of wind energy capacity has been developed or planned. And the results confirm that RPS policies are the most powerful tool that a State can use to promote wind energy. RPS have been particularly important for driving wind energy investment in Texas, Minnesota, and Iowa, where more than 1700 MW of new capacity has been developed to meet the requirements of just these three States. In addition, some portfolio standards such as those in Wisconsin and New Jersey have been directly responsible for wind development, not only within the State, but also in neighboring States. Ref. [28] describes the design of the Texas RPS and offers an early assessment of the program. The author concludes that an RPS can effectively spur renewables development and encourage competition among renewable energy producers. Furthermore, as mentioned in Ref. [35], RPS creates incentives for all renewable generators in a region, not just within a state.

Poland also has TGC scheme and Paper [36] studies the scheme and the key argument lies in the fact that that TGC can provide high investment incentives for RES especially for wind power and alleviate deployment barriers related to infrastructure, funding, and technology availability. In Ref. [37] Ringel points out that green certificates can contribute to increasing the share of green power production in Europe. He concludes that the quantity-based green certificates not only vouch for the fulfilment of the renewable energy goal, but also guarantee that this aim is precisely met.

Analytical analysis has been conducted by many researches. In Ref. [38] Brown and Busche analyses correlations between individual policies and increased renewable development. They find that existence of a renewable portfolio standard in a state is significantly correlated to higher wind-based electricity generation. And they declare that existence of an RPS is also significantly correlated to higher renewable percentages of overall electricity generation. In paper [39] Haitao and Nicholas introduce a new measure for the stringency of an RPS that explicitly accounts for some RPS design features that may have a significant impact on the strength of an RPS. They also investigate the impacts of renewable portfolio standards on in-state renewable electricity development using panel data and the new measure of RPS stringency, and compare the results with those when alternative measures are used. Using this measure, they confirm that, on average, RPS policies have had a significant and positive effect on in-state renewable energy development. And the authors of paper [40] discuss the analytical effects of introducing green certificates and the corresponding quotas as regulatory mechanisms to ensure a certain deployment of renewable energy. It is shown that it is always optimal to reach a renewable energy deployment goal by the use of green certificates.

Many simulations of models support the effectiveness of TGC and RPS too. Paper [41] analyzes pattern of prices for Tradable Green Certificates to encourage electricity generation from wind. The analysis shows a strikingly consistent pattern in the beginning years of the market. TGC prices consistently climbing to the price cap and remaining there for several years. The simulations show that wind investors eventually react with increased construction that allows the wind generation to exceed the RPS targets. In Ref. [42], Menz and Vachon econometrically analyze the contribution to wind power development of several state-level renewable energy policies. They find that RPS has a statistically significant effect on wind capacity deployment. And a dynamic simulation model that helps to study the combined competitive electricity and TGC markets has been presented in Ref. [43]. The result shows that TGC can make incentives for wind capacity investment.

3.3. Stimulus to renewable resource diversity

What's more, renewable resource diversity can be encouraged by specifically designed RPS programs. Generally, two approaches are feasible:

1) banding (also referred to as “multipliers”)
2) carve-out (also referred to as “set-asides”)

To support a broader set of renewable energy technologies, an increasing number of American states have applied one or both of

these two mechanisms. Ref. [27] records the design and early experience of state-level RPS programs in the United States, which have been specifically tailored to encourage a wider diversity of renewable energy technologies, solar energy in particular. As shown in the paper, roughly 61% of the more than 37 GW of non-hydro renewable energy capacity added from 1998 to 2009 in the United States occurred in states with an active or impending RPS compliance. RPS programs have already been proven to be an important stimulus for solar energy deployment. Using a panel data from 1991 to 2007 over 50 US states and a state fixed-effects model with state-specific time-trends, paper [44] estimates the effects of state policies on the penetration of various emerging renewable electricity sources. It finds out that RPS has a positive impact on geothermal and solar.

Experiences from other countries also support that RPS programs encourage renewable resource diversity. In Ref. [45], authors study policies related to renewable energy development and deployment in Japan. The results illustrate that RPS program favors renewable energy options such as waste-fired (biomass) generation. Besides, paper [46] conducts an analysis of the essence of electricity generation market and green certificate market. The author points out that TGC can promote resource allocation of renewable energy and avoid inadequate resources use due to mandatory quotas, encouraging renewable energy producers to join the market.

3.4. Impacts of voluntary renewable energy certificate

In general, renewable energy certificates include two markets: compliance and voluntary certificate markets. The aforementioned TGC is based on RPS, and it refers to compliance market. In the U.S., institutions and consumers can also purchase renewable energy to match their electricity needs on a voluntary basis in voluntary green certificate markets [47]. And the vast majority of U.S. voluntary green power market is based upon wind power projects to supply these RECs [48].

Heeter et al. [49] reviews market trends of voluntary renewable energy in 2011 and estimates market performance of voluntary REC. It turns out that voluntary REC markets continue to exhibit growth and provide a stimulus for development of renewable energy.

3.5. Summary and comparison

In brief, TGC and RPS have been regarded as a market-based environmental subsidy [41]. It is used to increase the share of renewable generations in a predictable way, at lower costs compared to direct subsidies and to make promotion of a diverse mix of RESs, some of which may be more attractive from social, economic and ecological perspective.

Apart from increasing the share of RES and promoting renewable resource diversity, RPS is also beneficial to innovation. Ref. [50] examines the effect of environmental policies on technological innovation in the specific case of renewable energy. The results indicate that REC targets significantly and positively encourage innovation for wind power.

Some literatures on RPS and TGC schemes have compared them with feed-in tariffs. Generally, comparisons lie in the following aspects: (1) efficacy of promoting growth and meeting ambitious target [18,24,51], (2) economical efficiency [51–53], (3) equity and institutional feasibility [22], (4) Effectiveness through risk reduction [54], and (5) fostering RES innovation [50,52,55]. And a brief summary of these comparisons is presented in Table 5. Although performances of policies concerning different aspects are different, as for promoting renewable energy, FIT and RPS both perform excellently.

Table 5
Comparisons between FIT and RPS/TGC.

Performance	FIT	RPS/TGC
Efficacy	good	good
Efficiency	higher cost than RPS	least cost
Risk	low	high
Induce innovation	superior than RPS [55]	inferior

4. Emission trading scheme

Emission trading is a market-based approach which is mainly used to control pollution by providing economic incentives for achieving reduction targets of pollutants [56]. Globally, many countries have adopted emission trading schemes, among which the most successful and the largest market is the EU Emissions Trading Scheme (EU ETS). Studies have shown that besides mitigation of emission, ETS also provides benefits for renewable energy.

The potential impact of introduction of carbon emission trading on China's power sector and the impact of different allocation options of allowances are discussed in Paper [57]. It is found that the relative cost of different power generation technologies is influenced by carbon price in emission trading. The proportion of environmental friendly technologies is also significantly increased. Expensive solar power generation in particular develops significantly, with final proportion increasing by 14%. Besides, it is mentioned in Ref. [58] that auctioning of emission allowances will make electricity production with use of renewable energy more attractive compared to those using fossil fuels.

Impacts of emission trading on investment decision are also explored, Brauneis et al. [59] evaluate the effects of carbon price floor on the investment decision of a profit maximizing energy producer and show us that it can stimulate the adoption of low-carbon technologies. Li and Yu [60] studies the impact of emission trading on carbon, electricity and renewable markets. The results illustrate that renewable markets will force a fixed quantum of renewable energy into the supply mix in the presence of ETS. And generation expansion planning problem is investigated in Paper [61] using Lagrangian Relaxation method and a mathematical model. The analysis suggests that green certificates and emission rights trading may act as a powerful drift toward the adoption of renewable energy sources.

5. Conclusions and an outlook for future study

This paper has mainly presented a review on promoting share of renewable energy by green-trading mechanisms in power system. In order to promote renewable energy, many policies have been implemented by national governments, and we mainly focus on feed-in-tariff, tradable green certificate system and emission trading to study their incentive effects on renewable energy generation. Our review suggests that (1) feed-in tariffs are useful to promote renewable technology by setting specific guaranteed tariffs; (2) RPS and TGC increase the share of renewable energy power such as wind, geothermal, solar and biomass in a predictable way and lead to renewable resource diversity; (3) emission trading also provides stimulus for development of renewable energy besides mitigation of carbon emission.

There are also some future works that we can make effort on. To begin with, the review discussed above considers the promotion effect of three different green-trading mechanisms. However, they perform not identically regarding economical efficiency and equity. And the electricity pricing mechanisms in different

countries vary, for example, Chinese electricity pricing mechanism differs from those in Europe and USA. In consequence, policy choices and details of mechanisms need to be studied further to cater for renewable energy policies of specific countries. Review article [62] provides useful information for the implementation of renewable portfolio standard in China, and can be used as a good reference. Secondly, many countries have introduced a variety of green trading mechanisms to facilitate the development of renewable energy, and they may influence each other to some extent. Although there are already some literatures researching on the interaction between emission trading and tradable green certificates [40,63–68], the interaction among policy mix awaits to be studied more systematically.

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